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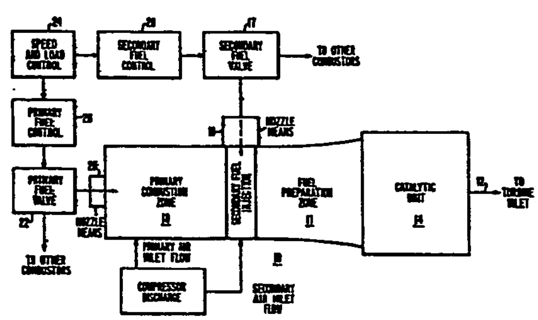
(71) Applicant: WESTINGHOUSE ELECTRIC CORPORATION, Westinghouse Building Gateway Center, Pittsburgh Pennsylvania 15222 (US)

(72) Inventor: Pillsbury, Paul Walter, 406 Hawthorne Lane, Wallingford Pennsylvania (US)
Inventor: DeCorso, Serafino Mario, 1261 Post House Lane, Media Pennsylvania (US)

(74) Representative: Holzer, Rupprecht, Dipl.-Ing., Philippine-Welser-Strasse 14, D-8900 Augsburg (DE)

(54) **Catalytic combustor having secondary fuel injection for a stationary gas turbine.**

(57) A combustion turbine is provided with a plurality of catalytic combustors (10) each of which includes a combustor basket (40) coupled to a transition duct (38) through a catalytic unit (14, 36). The combustor basket (40) is provided with a primary nozzle (20, 44) at its upstream end to provide fuel for conventional combustion and dilution in a primary zone (18, 50). A plurality of secondary nozzles (16, 46) are provided for fuel injection through the basket sidewall at the downstream end of the primary zone. A fuel preparation zone (11, 54) is provided within the basket from the secondary fuel injection location (58) to the catalytic unit (14, 36) to provide uniform mixing of the fuel in the gas flow. During startup and lower loads, primary fuel is supplied to energize the turbine without secondary fuel. At a predetermined load, secondary fuel flow is initiated and primary fuel is cut back to a level sufficient to provide any preheat needed to raise the secondary fuel mixture to a level required for catalytic activity.



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PATENTANWALT
DIPL. ING. R. HOLZER
PHILIPPINE-WELSER-STRASSE 14
ZUGELASSENER VERTRETER VOR DEM
EUROPÄISCHEN PATENTAMT
PROFESSIONAL REPRESENTATIVE
BEFORE THE EUROPEAN PATENT OFFICE
MANDATAIRE AGRÉÉ PRÈS L'OFFICE
EUROPÉEN DES BREVETS
8900 AUGSBURG
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CATALYTIC COMBUSTION SYSTEM FOR STATIONARY GAS TURBINE

TITLE MODIFIED
see front page

This invention relates to stationary combustion turbines and more particularly to the implementation of catalytic combustion in such turbines to characterize the turbine operation with low NO_x emissions.

Various schemes have been undergoing development to provide combustion turbines which generate electric power or run industrial processes without exceeding NO_x emission limits. The use of catalytic combustion is a promising approach because catalytic combustion can occur at about 2300°F to 2500°F to produce a high turbine inlet temperature for turbine operating efficiency without any significant side effect NO_x generation from reactions between nitrogen and oxygen. In contrast, conventional flame combustion at about 4500°F results in NO_x generation which typically exceeds the limits set in more restrictive areas such as California and Japan.

In the operation of the conventional turbine combustion process, compressor discharge air is supplied at an elevated temperature to support the combustion of fuel supplied through one or more nozzles at the upstream end of multiple combustor baskets. Combustion products are directed through ducting to the turbine blades.

For catalytic combustion to occur, fuel and air must be mixed and supplied to the entry side of a catalyst unit at an elevated temperature determined by chemical

characteristics of the catalyst employed in the catalyst unit. In turn, the temperature of the compressor discharge air used in the fuel-air mix depends on the compression ratio of the compressor which is based on overall turbine design considerations. For any particular compressor design, the compressor discharge temperature also depends on the operating point of the turbine during the startup and load operating modes. Generally, as turbine speed or load increases, the compressor discharge air temperature increases.

Thus, in applying a catalytic combustion process to combustion turbines a need exists to provide for turbine system functioning where compressor discharge air is supplied at a temperature below the minimum temperature needed for catalytic reaction. In the known prior art, U.S. Patents 3,928,961 and 4,112,675 appear to address this need with various limitations.

It is an object of this invention to provide a novel catalytic combustion system for a stationary gas turbine with a view to overcoming the deficiencies of the prior art.

The invention resides in a catalytic combustion system for a stationary gas turbine, characterized in that it comprises a combustor basket having a tubular sidewall defining therein a primary combustion zone, primary nozzle means for supplying fuel for combustion in the primary zone, and a secondary zone downstream from the primary combustion zone, secondary means for injecting secondary fuel and air into the secondary zone for mixing with the primary combustion product flow to provide a fuel-air mixture at a combustor basket outlet sufficiently mixed and heated to undergo catalytic reaction, a catalytic unit, means for supporting said catalytic unit to receive the outlet flow from said combustor basket, and means for supplying fuel to said primary nozzle means and said secondary injecting means so that secondary fuel is supplied to energize the turbine when conditions for cataly-

tic reaction are achieved and so that primary fuel is supplied to energize the turbine when no secondary fuel is being supplied and to energize the turbine and preheat the secondary fuel-air mix as needed when secondary fuel is being supplied.

As described above, the catalytic combustor for a statinary gas turbine comprises a combustor basket coupled to a catalytic unit and having a sidewall that defines an upstream primary combustion zone in which fuel is burned to produce hot preheating gases in a downstream secondary zone. Secondary fuel injection means is mounted relative to a casing of the turbine and the combustor basket to provide for convenient secondary fuel assembly removal. The secondary fuel is injected for mixing with air and the hot internal gases to provide a well mixed fuel-air mixture for combustion in the catalytic unit when catalytic reaction conditions are reached.

The invention will become readily apparent from the following description of exemplary embodiments thereof when taken in conjunction with the accompanying drawings, in which:

Figure 1 schematically shows a catalytic combustion system arranged to operate a stationary gas turbine in accordance with a preferred embodiment of the invention;

Figure 2 shows an elevational view of the catalytic combustion system disposed in a turbine and structure;

Figure 3 shows an enlarged view of the combustion system of Figure 2;

Figure 4 shows a modification of the combustor basket shown in Figure 2, which is provided with a necked down portion to promote secondary fuel-air mixing.

More particularly, there is shown in Figure 1 a generalized schematic representation of the catalytic combustion system according to the preferred embodiment of the invention.

A turbine or generally cylindrical catalytic combustor 10 is combined with a plurality of like combustors (not shown) to supply hot motive gas to the inlet of a turbine (not shown in Figure 1) as indicated by the reference character 12. The combustor 10 includes a catalytic unit 14 which preferably includes a conventional monolithic catalytic structure having substantial distributed catalytic surface area which effectively supports catalytic combustion (oxidation) of a fuel-air mixture flowing through the unit 14. Typically, the catalytic structure is a honeycomb structure having its passages extending in the gas flow direction.

The combustor 10 includes a zone 11 into which fuel, such as oil, is injected by nozzle means 16 from a fuel valve 17 where fuel-air mixing occurs in preparation for entry into the catalytic unit 14. Proper mixing preferably entails vaporization of 80% to 90% of the injected fuel for efficient and effective catalytic reaction.

Typically, the fuel-air mix temperature (for example 800°F) required for catalytic reaction is higher than the temperature (for example 700°F) of the compressor discharge air supplied to the combustors from the enclosed space outside the combustor shells. The deficiency in air supply temperature in typical cases is highest during startup and lower load operation.

A primary combustion zone 18 is accordingly provided upstream from the fuel preparation zone 11 within the combustor 10. Nozzle means 20 are provided for injecting fuel from a primary fuel valve 22 into the primary combustion zone 18 where conventional flame combustion is supported by primary air entering the zone 18 from the space within the turbine casing through openings in the combustor wall.

As a result, a hot gas flow is supplied to the catalytic fuel preparation zone where it can be mixed with the fuel and air mixture in the fuel preparation zone 11

to provide a heated fuel mixture at a sufficiently high temperature to enable proper catalytic unit operation. In this arrangement, the fuel injected by the nozzle means 16 for combustion in the catalytic unit is a secondary fuel flow which is mixed with secondary air and the primary combustion products which supply the preheating needed to raise the temperature of the mixture to the level needed for entry to the catalytic unit.

The catalytic combustion system is operated by a generally conventional analog or digital computer or digital/analog speed and load control 24 which operates the primary and secondary fuel valves 22 and 17 through conventional electropneumatic valve controls 26 and 28 respectively. The control 24 is preferably arranged to operate the primary fuel system to energize the turbine through primary combustion only during startup and, after synchronization, during loading up to a predetermined load level. Thereafter, primary combustion is reduced by primary fuel cutback as secondary fuel flow is initiated by the control 24 to provide for turbine energization primarily through catalytic combustion.

During the higher load catalytic combustion phase of operation, primary combustion occurs at a reduced level to provide secondary fuel-air mixture preheat as previously described. Further, as catalytic activity drops off with turbine operating time, compensatory increases in primary combustion are instituted through appropriate offset adjustments in the controls 26 and 28. More description is presented subsequently herein on the coordinated operation of the primary and secondary fuel valves.

During the startup/lower load phase of operation, primary combustion provides the turbine energization needed to drive the turbine operation to the point where motive gas temperatures are sufficient for sustained catalytic combustion operation.

During the higher load phase of operation, fuel flow rates are increased but only a small part of the total fuel is supplied as fuel for primary combustion and the rest of the fuel is supplied as secondary fuel for catalytic combustion. Emission of NO_x during the higher load phase from the relatively small amount of primary fuel combustion used to provide preheating of the secondary fuel-air mixture thus is also well below the most restrictive emission limits.

In Figures 2 and 3, there is shown a structurally detailed catalytic combustion system 30 embodying the principles described for the combustor 10 of Figure 1. Thus, the combustion system 30 generates hot combustion products which pass through stator vanes 31 to drive turbine blades (not shown). A plurality of the combustion systems 30 are disposed about the rotor axis within a turbine casing 32 to supply the total hot gas flow needed to drive the turbine.

The catalytic combustor 30 includes a combustor basket 40, a catalytic unit 36 and a transition duct 38 which directs the hot gas to the annular space through which it passes to be directed against the turbine blades.

The combustor basket 40 is mounted on the casing 32 by bolt means 42 and preferably is provided with a primary and plural (six) secondary sidewall fuel nozzles 44 and 46. Fuel supplied through the primary nozzle 44 (readily removable for maintenance) is mixed with primary combustion support air, which enters the basket 40 through sidewall scoops 48 (or openings), and burned in a primary combustion zone 50 to provide hot gas for driving the turbine or preheating a downstream fuel-air mixture to the level required for catalytic reaction. Primary combustion support air also enters the basket 40 in this case through swirlers 52 which are disposed coaxially about the primary nozzle 44. Dilution air enters the zone 50 primarily through scoops 49. The length of the primary zone 50 accordingly is sufficient to provide the space needed for

primary combustion to occur followed by the space needed for mixing of the primary combustion products with dilution air. The primary zone sidewall is conventionally structured from a plurality of sidewall rings which are securely held together in a telescopic arrangement by corrugated spacer bands. The spacer bands thus provide an annular slot between adjacent sidewall ring members through which air is admitted to cool the internal sidewall ring surfaces. As a result, the cross-section of the primary zone increases slightly in the downstream direction.

Primary ignition is provided by a conventional spark igniter in a tube 35 in one or more of the combustors 40. Cross flame tube connectors indicated by reference character 37 are employed to ignite the other combustors 40.

The supplemental use of a conventional burner to produce part of the total fuel combustion in the system 30 enables compensation to be made for dropoff in catalytic activity with turbine operation time. As previously noted, the ratio of conventional combustion to catalytic combustion is sufficient under all higher output operating conditions to achieve the needed combustion assistance without the production of an unacceptable NO_x penalty.

Gases flow downstream within the combustor basket 40 from the primary combustion zone 50 to the entry to a secondary zone 54 where the secondary fuel nozzles 46 inject fuel along an injection plane preferably with respective surrounding jets of air through sidewall scoops 55 for mixing with the primary gas flow. The resultant mix expands as it passes through an outwardly flared diffuser 56 which forms an end portion of the basket 40. It then enters a catalytic reaction element 27 in the catalytic unit 36.

Proper penetration of secondary air jets into the combustor is important from the standpoint of fuel/air mixing because the jets carry the secondary fuel with

them. If penetration is excessive, the center of the catalyst element receives too much fuel; if too little penetration is obtained, the edges of the catalyst receive too much fuel. For optimum mixing, the maximum penetration should be 33% of the tubular combustor diameter.

With proper jet penetration, good atomization of secondary fuel (such as 30 micron droplets) is the key to achieving rapid fuel vaporization. With preheat to 800°F, 30 micron fuel droplets are normally completely vaporized within a few inches of the injection plane, but even drops as large as 90 microns, of which there would normally be very few, should be more than 99% vaporized at the catalyst inlet.

The diffuser 56 is employed because a smaller path diameter is needed for satisfactory fuel mixing in the combustor basket 40 as compared to the path diameter needed for catalytic combustion. Thus, injection of secondary fuel into a smaller diameter basket provides improved fuel/air mixing and better fuel/air uniformity across the face of the catalyst. On the other hand, the use of a larger basket diameter enables use of a larger catalyst diameter which results in a lower catalyst inlet velocity and produces a lower pressure drop and improved combustion efficiency.

The flared shape of the diffuser 56 is preferably formed to prevent hot gas flow separation (i.e. to prevent turbulent layer formation near the diffuser wall). Back pressure from the catalyst structure provides forces needed to expand gas streamlines out to the diffuser wall and prevent turbulent layer buildup.

To protect the catalytic element and the combustor basket 40, the system operates so that the residence time for the gaseous mixture (in this case, preheated to 800°F) in the secondary fuel preparation zone 54 is less than the ignition delay time from the primary zone 50. In this way, flame is contained in the primary combustion zone 50 away from the catalytic element 36. Thus,

the secondary fuel injection plane 58 is spaced from the catalyst face by a distance which is sufficient to permit proper fuel mixing (substantial uniformity across the catalyst face) and preparation for the catalyst but which is less than the critical distance which allows the fuel-air mixture to auto-ignite before it crosses the secondary zone 54 into the catalytic element. Normally, the fuel-air mixture is driven across the zone 54 within several milliseconds to avoid auto-ignition.

The secondary fuel nozzles 46 are supported preferably with a predetermined spacing outwardly from the combustor sidewall. In this case, the nozzles are angled for transversely directed fuel injection with a predetermined angle of spread.

The cooling air also atomizes the fuel to a fuel fog as it is injected through the scoops 55 into the combustor fuel preparation zone 54. An additional air jet joins the nozzle flow in the scoop 55 and provides any additional air needed to achieve the desired fuel-air ratio (preferably lean) in the fuel preparation zone 56. The scoop size and nozzle placement both can be varied to modify the amount of such air jet flow.

The diameter of the catalytic element is determined mainly by the maximum allowable reference gas velocity for complete emissions burnout at an acceptable pressure loss. Higher gas velocities require longer catalyst beds and result in higher emissions. The mass transfer units required for complete emissions burnout are inversely proportional to the square root of reference velocity in laminar flow, but the effect of reference velocity on the mass transfer rate decreases with an increase in channel Reynolds number. Thus, the maximum allowable reference velocity is limited in turbulent flow by the restriction of pressure losses. However, the low limit boundary of reference velocity for the region of operability may be determined by flashback considerations in the fuel preparation zone.

The catalytic element includes a can 30 within which a catalytic honeycomb structure is conventionally supported by suitable means. The catalyst characteristics can be as follows:

DATA FOR DXE-442 CATALYST

I. Substrate	
Size	(2" + 2") long- (¼" gap between two sections)
Material	Zircon Composite
Bulk Density	40-42 lb/ft^3
Cell Shape	Corrugated Sinusoid
Number	256 $Channels/in^2$
Hydraulic Diameter	0.0384"
Web Thickness	10 ± 2 mils.
Open Area	65.5%
Heat Capacity	0.17 BTU/lb, °F
Thermal Expansion Coefficient	2.5×10^{-6} in/in, °F
Thermal Conductivity	10 BTU, in/hr, ft^2, °F
Melting Temperature	3050°F
Crush Strength	
Axial	800 PSI
90°	25 PSI
II. Catalyst	
Active Component	Palladium
Washcoat	Stabilized Alumina

Figure 4 shows a modification of the combustor basket 40 shown in Figures 2 and 3. The combustor basket 40 is pinched-in to a diameter of, for example, 7.8 inches to accelerate the flow from the primary combustion zone 50 to 200 ft/sec. at the secondary fuel injection plane 58 so as to promote secondary fuel-air mixing. Recent studies have shown that flame will not propagate upstream in a

mixture of the secondary fuel and air if the velocity is above 200 ft/sec.

With operation of the catalytic combustors 30 in the manner described, hot motive gases are supplied to the turbine inlet essentially free of oxides of nitrogen and at efficient operating temperatures above 2200°F. As indicated by the following table, primary combustion occurs throughout the startup mode and during initial loading until 47% load is reached. At that point, the control sequences the secondary fuel valve into operation and cuts back on the primary fuel supply. Further load increases are then met by increases in secondary fuel.

CATALYTIC COMBUSTOR OPERATING CONDITIONS

LOAD CONDITIONS	Comb. Inlet Temp. (°R)	Comb. Inlet Press. (Psia)	Comb. Air Flow (lb/s)	Pri. Fuel Flow (lb/s)	Sec. Fuel Flow (lb/s)	Bypass Air %	Cat. Inlet Temp. (°R)	Cat. Exit Temp. (°R)	Comb. Exit Temp. (°R)	Cat. Inlet Vel. (ft/s)	P Comb. %	P Cat. %	P Total %	I.G.V. Position Degrees
Cranking	555	15.7	3.38	0.0	0.0	6.08	555	555	555	30.1	.90	1.29	2.18	22
Ignition	565	17.3	2.81	.045	0.0	11.58	1811	1811	1678	70.6	.46	4.13	4.59	22
100 sec	668	25.6	6.38	.104	0.0	8.90	1875	1875	1777	116.6	1.36	6.19	7.55	22
200 sec	786	41.0	11.06	.178	0.0	7.41	1939	1939	1860	133.3	1.94	5.28	7.22	22
300 sec	881	67.9	19.69	.222	0.0	6.46	1691	1691	1641	126.4	2.57	4.54	7.10	22
400 sec	943	89.7	26.25	.255	0.0	6.23	1639	1639	1598	124.1	2.81	4.40	7.21	22
500 sec	1033	121.7	36.88	.238	0.0	5.88	1496	1496	1470	117.9	3.33	4.21	7.53	0
600 sec	1056	134.6	40.56	.253	0.0	5.84	1503	1503	1478	117.8	3.37	4.16	7.52	0
Idle	1092	144.7	44.23	.286	0.0	5.84	1553	1553	1527	123.8	3.58	4.41	7.99	0
20%	1103	153.9	44.23	.416	0.0	6.04	1764	1764	1726	131.9	3.18	4.44	7.63	0
40%	1116	163.1	44.23	.554	0.0	6.23	1983	1983	1932	139.5	2.86	4.47	7.32	0
47% Bef. Trans.	1120	166.1	44.23	.604	0.0	6.30	2060	2060	2004	142.2	2.76	4.48	7.24	0
47% Aft. Trans.	1046	120.9	31.46	.107	.496	6.03	1260	2334	2264	85.5	2.48	3.44	5.92	37
60%	1102	149.7	36.57	.098	.602	5.95	1260	2380	2311	80.3	2.30	3.05	5.35	22
71%	1130	174.4	44.23	.1	.685	5.86	1260	2319	2255	83.5	2.55	3.18	5.73	0
80%	1137	178.7	44.23	.097	.757	5.91	1260	2420	2351	81.4	2.44	3.14	5.58	0
Base	1149	187.3	44.23	.095	.926	6.03	1260	2653	2572	77.7	2.24	3.11	5.35	0
Peak	1155	191.1	44.23	.094	1.005	6.09	1260	2760	2673	76.2	2.16	3.11	5.26	0

ISO Day, Sea Level, No. 2 Fuel Oil
Upstream Effective Area - 45.76 in , Downstream Effective Area - 1.90 in
Catalyst Diameter - 16 inches
Fixed Bypass

IDENTIFICATION OF REFERENCE NUMERALS USED IN THE DRAWINGS

LEGEND	REF. NO.	FIGURE
SECONDARY FUEL VALVE	17	1
PRIMARY FUEL VALVE	22	1
SPEED AND LOAD CONTROL	24	1
PRIMARY FUEL CONTROL	26	1
SECONDARY FUEL CONTROL	28	1

PATENTANWALT
DIPL. ING. R. HOLZER
PHILIPPINE-WELSER-STRASSE 14
ZUGELASSENER VERTRETER VOR DEM
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8900 AUGSBURG
TELEFON 0821/516475
TELEX 532202 PATOL D

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What we claim is:

1. A catalytic combustion system for a stationary gas turbine, characterized in that it comprises a combustor basket having a tubular sidewall defining therein a primary combustion zone, primary nozzle means for supplying fuel for combustion in the primary zone, and a secondary zone downstream from the primary combustion zone, secondary means for injecting secondary fuel and air into the secondary zone for mixing with the primary combustion product flow to provide a fuel-air mixture at a combustor basket outlet sufficiently mixed and heated to undergo catalytic reaction, a catalytic unit, means for supporting said catalytic unit to receive the outlet flow from said combustor basket, and means for supplying fuel to said primary nozzle means and said secondary injecting means so that secondary fuel is supplied to energize the turbine when conditions for catalytic reaction are achieved and so that primary fuel is supplied to energize the turbine when no secondary fuel is being supplied and to energize the turbine and preheat the secondary fuel-air mix as needed when secondary fuel is being supplied.

2. A catalytic combustion system as set forth in claim 1 characterized in that said combustor basket includes a downstream diffuser end portion having a sidewall which defines an expanding path for the fuel-air mix over at least part of the secondary zone.

3. A catalytic combustion system as set forth in claim 1 or 2 characterized in that said combustor

basket includes a portion which necks inwardly downstream along the primary zone upstream along the secondary zone to provide a reduced cross-section at the secondary fuel injection location for acceleration of the primary combustion product flow and consequent promotion of fuel-air mixing.

4. A catalytic combustion system as set forth in claim 1, 2 or 3 characterized in that said secondary injecting means includes nozzle means mounted with each nozzle outlet located externally of said basket sidewall for fuel injection through associated sidewall openings.

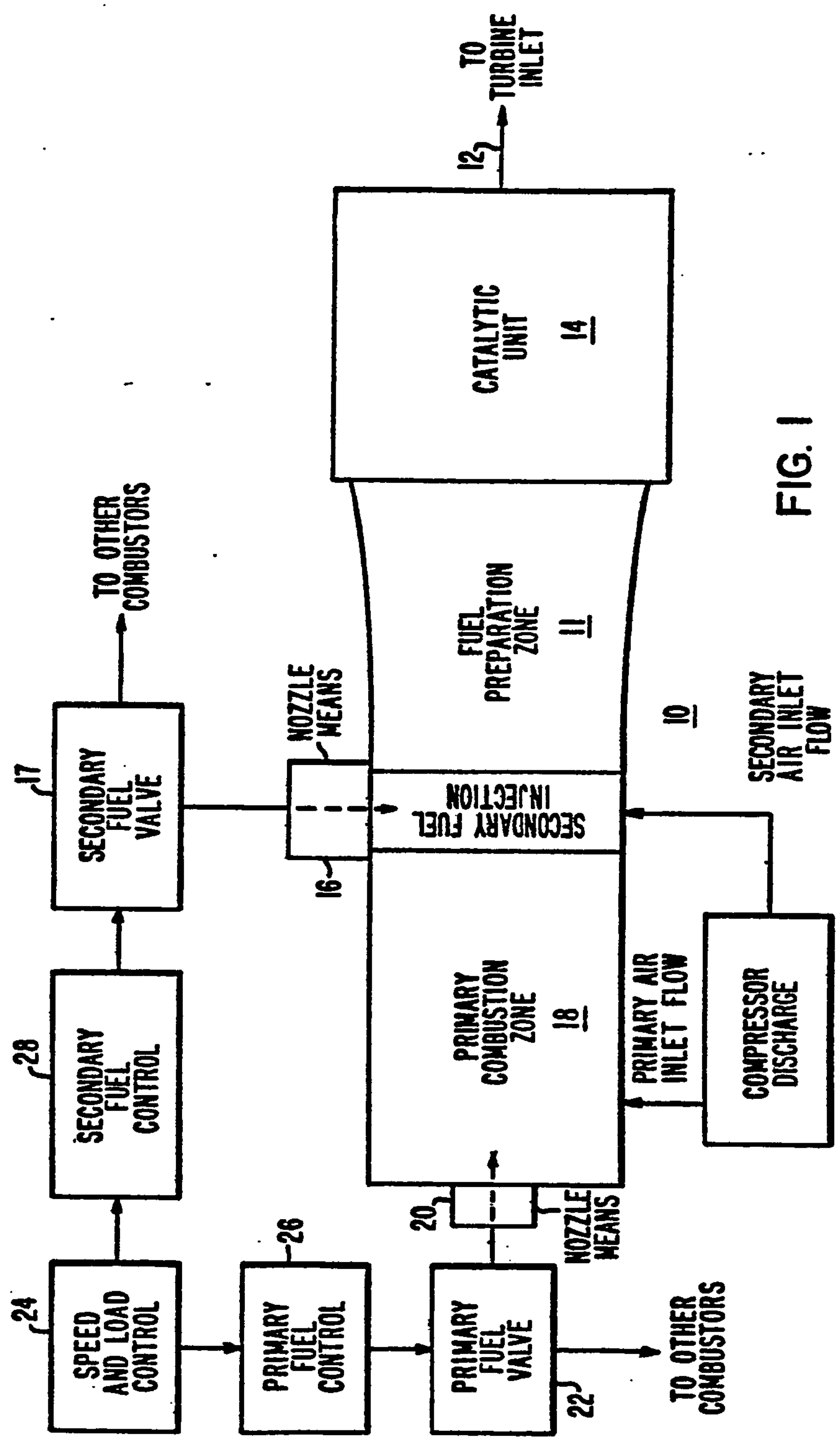
TO TURBINE INLET
12
CATALYTIC UNIT
14
FUEL PREPARATION ZONE
11
10
SECONDARY AIR INLET FLOW
TO OTHER COMBUSTORS
17
SECONDARY FUEL VALVE
NOZZLE MEANS
SECONDARY FUEL INJECTION
16
28
SECONDARY FUEL CONTROL
PRIMARY COMBUSTION ZONE
18
PRIMARY AIR INLET FLOW
COMPRESSOR DISCHARGE
24
SPEED AND LOAD CONTROL
26
PRIMARY FUEL CONTROL
20
NOZZLE MEANS
PRIMARY FUEL VALVE
22
TO OTHER COMBUSTORS

FIG. 1

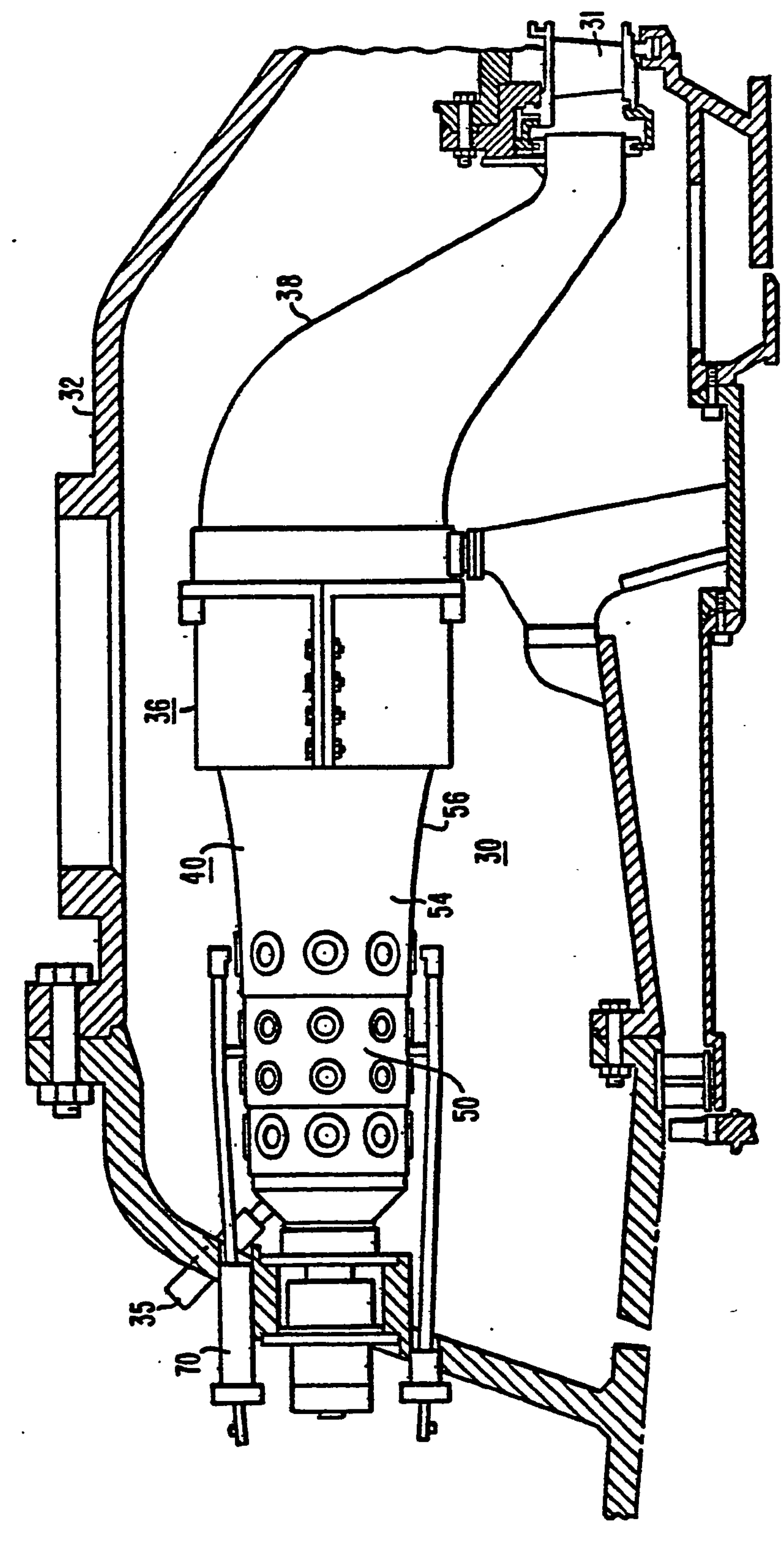

FIG. 2

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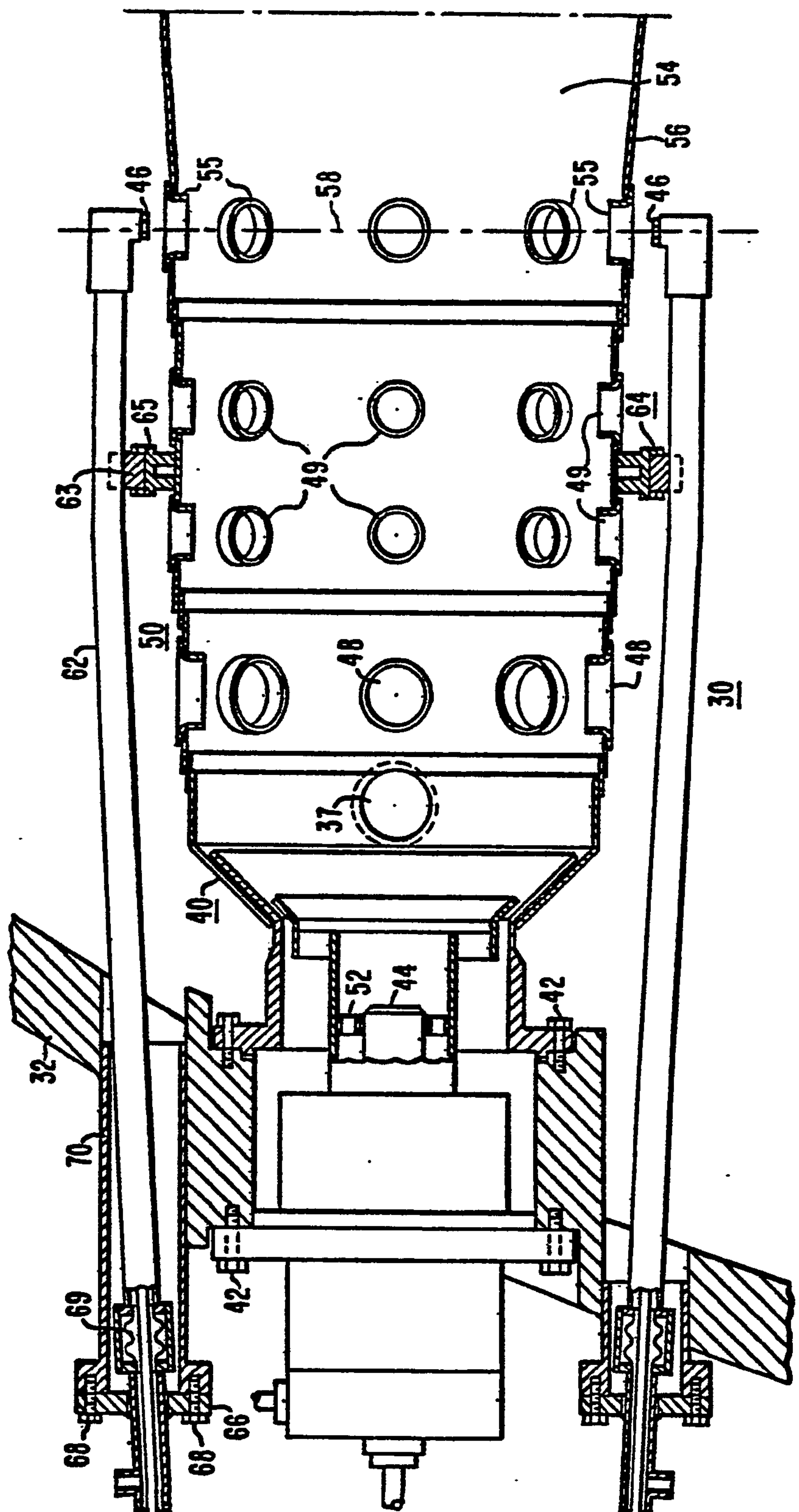

FIG. 3

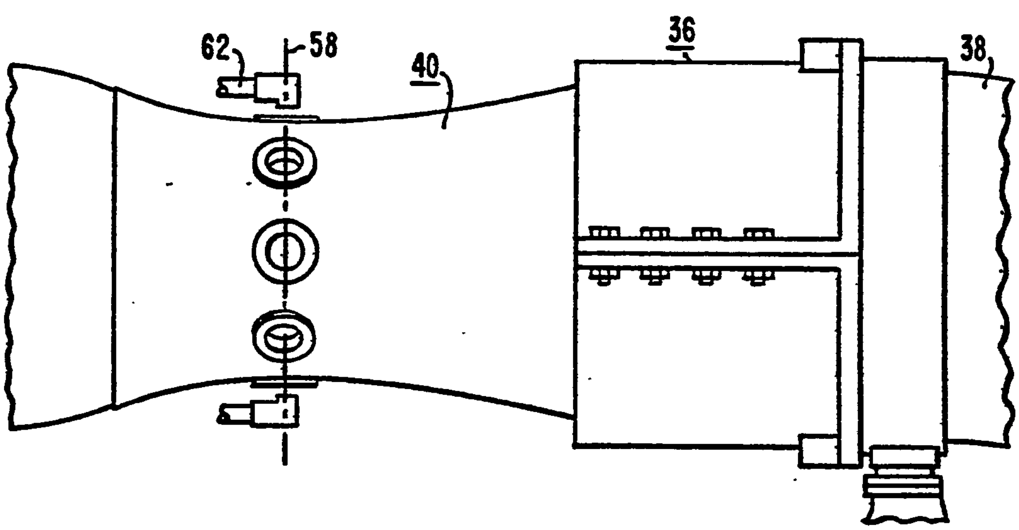

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

0062149

Application number

EP 82101111.1

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
X	GB - A - 1 575 427 (ENGELHARD MINERALS & CHEMICALS CORP.) + Fig. 2 + --	1,2,4
X	GB - A - 2 040 031 (GENERAL ELECTRIC CO.) + Fig. 1,2,4 + --	1,3,4
D,A	US - A - 4 112 675 (PILLSBURY et al.) + Totality + --	1
D,A	US - A - 3 928 961 (PFEFFERLE) + Totality + ----	1

CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)

F 23 R 3/40
F 02 C 7/00

TECHNICAL FIELDS SEARCHED (Int.Cl. 3)

F 23 R 3/00
F 02 C 7/00

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
Y: particularly relevant if combined with another document of the same category
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	13-05-1982	PIPPAN